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Development work on acoustic transducers for underwater range tracking : summary report

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

Summary Report

DEVELOPMENT WORK ON ACOUSTIC TRANSDUCERS FOR UNDERWATER RANGE TRACKING

O.B. Wilson, Jr.

Department of Physics and Chemistry

Project Report 1975 - 1979

Approved for Public Release; Distribution Unlimited

Prepared for:
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eyport, Washington 98345

NAVAL POSTGRADUATE SCHOOL
Monterey, California

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A summary is given of the results of work by the author and several NPS students, carried out over a period of several years, on problems of designing electroacoustic transducers sutiable for use as sound sources in the 75 kHz acoustic tracking system on the underwater weapons test ranges at Keyport, WA.

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1. INTRODUCTION

Acoustic methods have for a long time proved useful for determining the position of objects submerged in the ocean and continue to be useful today, especially for monitoring the realistic testing of advanced underwater weapons (such as torpedoes) in the real ocean environment.

One method commonly used requires installation of a sound source on the underwater vehicle to be tracked. The source/vehicle is then tracked acoustically by hydrophones arrayed in fixed positions on the ocean bottom. The basic function is that of measuring the transit time of the sound wave from the source to different hydrophones. These transit times enable determination of distances and directions of arrival which, in turn, are triangulated to determine position, a series of which defines the vehicle's track.

As in most engineering problems, the requirements placed on an acoustic source used for tracking are often conflicting in nature, with the end result being an engineering compromise. For example, in order to achieve a broad pattern from a single radiating element, the element's dimensions must be small relative to the wavelength of the sound transmitted. However, in order to obtain the desired sound pressure level, the electroacoustic transducer element may have to be driven so hard that cavitation is induced in the water near the transducer or that electrical or mechanical breakdown of the transducer materials may occur.

In order to reduce the severity of the design compromise problems, several steps might be helpful. The radiation pattern could possibly be modified to more nearly fit actual operating requirements. Reducing localized sound pressure amplitudes and internal electrical and mechanical stresses might be possible through increase in surface area of the radiating parts. This step would entail a more complex radiating element and make essential the ability to predict the radiating characteristics of the transducer.

Early in the association between the Naval Undersea Warfare Engineering Station and the Naval Postgraduate School, we were informed of some of the problems with the undesirably short life and poor performance of transducers used for the 75 kHz acoustic tracking of torpedoes on the test ranges at Keyport. As a result, studies were initiated to explore other approaches to the transducer design problem with the hope that a better solution could be achieved.

Efforts have involved several faculty members, (G.L. Sackman, J.V. Sanders and O.B. Wilson) and a number of students, (R.R. Johnson, A.H.P. Shaw, V.U. Auns, J.L. Jarvis, A.L. Ford, O. Sevdik and T. Kiyar). Most of the work has been that of the students who performed it as part of the thesis research for their degree, M.S. in Engineering Acoustics, at the Postgraduate School.

In the following sections are presented our perception of the problem, a summary of work on several different approaches to a solution and some conclusions and recommendations.

II. PERCEPTION OF THE PROBLEM

Our perception of the nature of the clock transducer problem is indicated in this section. The NPS participants in this work received the information about the problem from conversations with many different individuals at NUWES. For this reason, our understanding may have been incomplete or in error. Also, it is recognized that requirements have changed with time since the beginning of this effort. It appears that the clock transducer problem exists primarily with the flush-faced 75 kHz projectors, that the major problems are short lifetimes, with the deterioration in performance showing most often in the form of reduced source level and deterioration in the radiated beam pattern.

Earlier, the requirements were that the clock electronics provide a pulse of about 400 watts of electrical power at 75 kHz of about 1.3 milliseconds duration with a period between pulses of about 1.3 seconds. At the present time, the phase shift keying (PSK) system with a 48 bit code requires a 5.3 millisecond pulse, a selectable repetition rate from four per second to one in four seconds and only about 250 watts of peak electrical power.

The earlier specifications for the clock transducer were given to us as shown in Figure 1, taken from NAVORD Drawing No. 2814382 (Ref. 1). Later, the minimum axial source level requirements were relaxed somewhat (Ref. 2) to 180 dB ref. 1 micropascal at 1 yard, with a concurrent increase in beam width, to 88° on each side of the normal. The current requirement on bandwidth is 70 to 80 kHz with a four dB increase in output with frequency over this band to compensate for the frequency dependent absorption in water.

It seems clear that this is a typical consequence of conflicting requirements often placed on underwater acoustic projectors. In this case, small size relative to the acoustic wavelength is needed to provide the broad beam width. A large source level is necessary to achieve a satisfactorily large signal-to-noise ratio at the receiver at the longest ranges.

The electronic source is started before torpedo firing and continues to run until the battery is exhausted or the torpedo is opened after recovery, or, with the current PSK system, until the built-in timer clock reaches the pre-set cut-off time. Thus, the transducer is often operated for extended periods after the torpedo has been recovered from the water. This removes the damping effects of the acoustic loading and increases the mechanical stresses in the transducer components, which are already highly stressed.

III. RADIATION PARAMETERS FOR TRANSDUCERS

An order of magnitude estimate of the acoustic effects of these specifications on the transducer may be obtained from the model of a uniformly driven circular piston set into a rigid plane baffle, which radiates into a half space of fluid. The relationship between various parameters is calculated easily using relationships given by Kinsler and Frey, "Fundamentals of Acoustics", (Ref. 3).

The sound pressure amplitude, P, from a circular piston source, which is vibrating uniformly in simple harmonic motion will depend on: (1) the range, r, from the source, because of divergence of the wave and absorption in the medium; (2) the velocity amplitude, U_o, of the piston; (3) the piston radius, a; (4) the angular frequency, ω, of the sound where $\omega = 2\pi f$ and f is the frequency in Hertz; (5) the density, ρ_o, and the sound speed, c, in the fluid and (6) the angle, θ, measured from the perpendicular axis of the piston face.

In the far field, where r is larger than a critical range, r_c, the pressure amplitude is given by the equation (which neglects absorption):

$$P = \frac{\rho_o \; c \; k \; \pi a^2 \; U_o}{2\pi r} \cdot \left[\frac{2 \; J_1(ka\sin\theta)}{ka\sin\theta} \right] \qquad \text{Eq. 1}$$

The propagation constant, $k = \omega/c = 2\pi/\lambda$, where λ is the acoustic wavelength. For a circular piston radiator, the American National Standards Institute's definition gives

$$r_c = \pi a^2/\lambda$$

It can be seen that the pressure amplitude is linearly dependent on the area and the velocity amplitude of the piston and that the pressure increases with frequency. The directional characteristics are all determined by the term in brackets, called the directivity function.

An example of a radiation pattern for such a piston is shown in Figure 2, taken from Ref. 2. This plots the far-field sound pressure level as a function of angle for three different values of ka. It can be seen that for small values of ka, or, equivalently, the ratio of piston radius to acoustic wavlength, a/λ, the radiation pattern into the half-space is broad and almost omnidirectional. As ka becomes larger, the pattern angular width becomes smaller and the axial level increases. Finally, when ka is even larger, secondary or minor lobes appear in the pattern.

Very often it is useful to remove the range dependence from the sound field, such as given by Eq. 1, by setting the range to one meter or one yard. The sound pressure level calculated for unit range is called the source level (SL). In most cases, a specification of SL for a projector refers to the maximum value, or the axial value. In this report, the source level along various angular directions is also of interest.

Two parameters which are very useful in describing the directional characteristics of a sound source are the directivity ratio, D, and its equivalent in decibels, the directivity index, DI, where $DI = 10 \log_{10} D$. D is the ratio of the maximum sound intensity, I_o, at a given range, r, to the average sound intensity, I_{avg}, for all angles at the same range

$$D = \frac{I_o}{I_{avg}} \qquad \text{Eq. 2}$$

If absorption is neglected, the average intensity can be written in terms of the power radiated, W, in watts, and the range, r, as

$$I_{avg} = \frac{W}{4\pi r^2} \qquad \text{Eq. 3}$$

There is also a simple relationship between the intensity of the sound and the sound pressure, since

$$I = \frac{P^2}{\rho c} \qquad \text{Eq. 4}$$

where P is the rms sound pressure amplitude.

These equations can be combined to give a value for the axial source level, SL, in terms of the directivity index, DI, and the acoustic power radiated, W.

$$SL = 171.5 + 10 \log W + DI \qquad \text{Eq. 5}$$

If W is in watts, this gives the axial source level in dB referred to one microPascal at one meter.

Another relationship which is useful in estimating the acoustic intensity in the fluid just in front of the piston is to divide the total radiated sound power, W, by the area of the piston face, πa^2.

$$I_{avg} = W/\pi a^2 \qquad \text{Eq. 6}$$

This is valid if the area of the piston is not too small compared to the sound wavelength.

These relationships and the two sets of specifications on beam width and source level have been used to calculate values of piston radius, acoustic power output and average acoustic intensity at the transducer. Although the model of a uniform piston is not a really accurate representation for the actual transducers in use, it should give correct order of magnitude estimates of these parameters. The results are presented in Table 1.

TABLE 1

Axial source level dB ref 1 Pa at 1 yard	Half angle Beamwidth	DI	a Cm	W Watts	I_{avg} $\frac{\text{Watts}}{\text{Cm}^2}$
193	78°(-10 dB)	8	0.9	22	8.6
180	89°(- 3 dB)	4	0.5	2.8	3.6

These average intensities appear to be rather large and lead to an expectation of possible cavitation effects at shallow depths. Urick (Ref. 4) gives data on cavitation thresholds for various frequencies, pulse lengths and hydrostatic pressures. It appears that the average intensities from the table are of the same order of magnitude as the thresholds for cavitation at shallow depths. Therefore, it seems likely that cavitation could be a limiting factor acoustic performance of the transducer, particularly at shallow depths or at high speeds at greater depths.

Another concern is whether the removal of the radiation loading upon recovery from the water causes the amplitude of the motion of the transducer to increase sufficiently to lead to structural failure of the transducer. This would be difficult to estimate, except for a specific configuration.

IV. ESTIMATION OF REQUIRED SOURCE LEVELS

An assessment of requirements for source level and radiation pattern for the clock transducer was made using the following model.

It is assumed that when the source is at its maximum depth, it will always be at least 200 feet (67 yards) above the receiving hydrophones. The assumed maximum horizontal range is 3700 feet (1230 yards). The actual angle between the normal to the transducer and the acoustic ray path to the hydrophone will, of course, vary with horizontal range, depth and climb and dive angle of the torpedo. The transmission loss is assumed to arise from spherical spreading and absorption. Assumption of a particular ambient noise level and a required signal to noise ratio or recognition differential for proper tracking permits a calculation of the required source level for the projector as a function of angle. Figure 3 illustrates the geometry for the calculation. It is more convenient to make computations as a function of angle and relative depth rather than in terms of horizontal range. Corrections can then be made for effects of dive and climb angles.

Referring to Figure 3, it is seen that the slant range, R_s, from the source to the receiving hydrophones is given by

$$R_s = \sqrt{R_h^2 + h^2} \qquad \text{Eq. 7}$$

where R_h is the horizontal separation and h is the vertical separation between source and receiver. The grazing angle for the sound path, θ, is given by

$$\theta = \tan^{-1} \frac{R_h}{h} \qquad \text{Eq. 8}$$

The transmission loss for propagation over the slant range path distance, R_s, is

$$T L = 20 \log R_s + a R_s \qquad \text{Eq. 9}$$

where a is the absorption coefficient, about 0.02 dB/yard (Reference 4) at 75 kHz.

For the purposes of this estimate, a moderately intense ambient noise level is assumed. Using data from Urick (Ref. 4) for sea state 3 and a 10 percent bandwidth, a noise level, NL, of 70 dB ref 1μPa results. A recognition differential (RD) is assumed to be 20 dB for the calculations. That is, it is assumed that the source level must be large enough so that the signal level is always larger than the noise level by at least 20 dB. Then,

$$S L - T L = N L + R D \qquad \text{Eq. 10}$$

For a given relative depth, the source level requirements can be expressed as a function of angle using the fact that

$$R_s = h/\cos \theta \qquad \text{Eq. 11}$$

Combining Equations 8, 9, 10 and 11, there results

$$S L (\theta) = N L + R D + 20 \log \left(\frac{h}{\cos \theta} \right) + a \cdot \frac{h}{\cos \theta} \qquad \text{Eq. 12}$$

Figure 4 presents results of calculations in graphical form for two extreme cases (h = 67 yards and h = 367 yards) and for one intermediate relative depth. This is a plot of minimum required source level as a function of radiation angle, θ, for horizontal ranges out to 1230 yards.

From the graphs of Figure 4, it can be seen that the minimum source level requirements are greatest by far at angles between 73° and 88°, which correspond to the largest slant ranges, and are much reduced at angles near zero, which correspond to the least slant ranges. The required maximum value of source level from this model, about 178 dB ref 1μPa at 1 yard at an angle of about 88°, corresponds well to the currently specified source level of 180 dB out to 88° (Ref. 2).

The accomodation for changes in attitude of the torpedo during maneuvers (reported to be as large as 30 degrees) must be made also. Thus, the actual source level must be nearly 180 dB for angles between 50 and 88 degrees and source levels between 0 and 50 degrees could be smaller than this by as much as 30 dB. This suggests a proposed specification like that shown in Figure 5.

Therefore, if most of the sound energy which would normally be radiated into the central 50 degree sector were redirected to that between 50 and 88 degrees, the total radiated power could be reduced by about one-third and the concomitant electrical and mechanical stresses on the transducer and the medium in front of it could be reduced by about 1.5 to 1.8 dB.

For other cases, where the ambient noise levels and required recognition differentials have values which are greater or lesser than those assumed in this example, corresponding increases or decreases in the source levels would be appropriate.

V. SUMMARY OF DESIGN AND DEVELOPMENT STUDIES

The main objective in the design studies was to explore means by which the radiation pattern from a flush-faced transducer could be formed and controlled to provide results similar in angular distribution to that shown in Figure 5. Secondary objectives include capability for achieving adequate source levels and operating frequency bandwidths. Other characteristics, which would be important in a choice of approach for a production unit, such as cost of manufacture, were not evaluated at this time.

Three technical approaches to obtaining radiation pattern control were used:

1. A distribution of small sources having differing phase and amplitude of motion;
2. Refraction effects at the transducer-water interface using materials with a high index of refraction;
3. Radiation from axially symmetric flexural waves in a plate.

The major part of these studies was conducted as part of the thesis research of a number of naval officer students. Reference to each is given in the following summaries. An abstract from each thesis is included as an appendix.

The work on the approach of using phase and amplitude shading of a distribution of sources for obtaining the desired beam pattern has been both theoretical and experimental.

CDR Roland Johnson (Ref. 5) adapted an existing closed-form solution for the radiation pattern for a uniform source mounted on a rigid cylindrical baffle to the computer calculation of patterns from rectangular and circular distributions of a number of discrete elements having different amplitudes and phases of motion. He was able to show that the results obtained for a rectangular configuration do reduce to results obtained by others for a specific case. Similar such tests were not available for the circular configurations. So far, these programs have not been used as design tools. Although they are for a more realistic boundary condition, the rigid cylinder, they do require considerably more computer time than do similar programs for a plane baffle. For this reason, further work has used a simpler but less realistic program.

LCDR Al Shaw (Ref. 6) did both theoretical and experimental work. Using a simpler program than did Johnson, Shaw calculated radiation patterns for a two element concentric circular sound source and then constructed a scaled model for tests. A frequency scaling of one-third was used in order to simplify the transducer construction problems. There was reasonable agreement between the computer calculated and measured radiation pattern shapes at the scaled frequency. Exceptionally wide major lobe widths were obtained. The results were considered to show that this design concept was a valid and viable one.

LCDR Vilnis Auns (Ref. 7) extended the work of Shaw by constructing and testing in the laboratory several models of concentric ring transducers which were resonant at about 75 kHz. Auns used a composite transducer construction method. These experiments showed that this approach to be feasible. Additional development would be needed to construct a prototype which could be tested on the Keyport ranges.

An experiment was conducted by Ford (Ref. 7) to explore the feasibility of the second approach to achieving broader beamwidths, that of using a high refractive index material. Ford used a resin which has a sound speed significantly smaller than that in water and in the resins commonly used for coupling between the transducer vibrating element and the water. He obtained a radiation pattern which was significantly more broad than that typical of the then currently produced transducers. A second experiment, conducted by personnel at Keyport (Ref. 8), using this same resin on a NTS transducer, confirmed the beamwidth effects, but the unit did not perform well with the PSK test, probably because of poor frequency bandwidth. The small sample size of these experiments and the negative result on the PSK test led to a decision to not continue work with this approach.

The interest in exploring the radiation from flexural vibrations of a disk came from our contacts with Mr. Michael Barlow, at NUWES. Earlier he had done some preliminary experiments with a flexural disk transducer which showed some favorable results.

The first work at NPS was that by LT Omer Sevdik (Ref. 9). Two models, both using a clamped edge disk driven at its center by a longitudinal vibrator were constructed and tested in the laboratory. These showed a great deal of promise, since it was found that a broad beam width radiation pattern could be achieved over a reasonably large frequency bandwidth. However, it was also found that the fluid loading has significant effects on the resonance frequencies of the plate and on the standing wave pattern of the flexural waves which could not be readily explained. It was concluded that additional fundamental knowledge was needed.

Therefore, experiments were conducted by LCDR James L. Jarvis (Ref. 10) in order to understand better experimentally the influence of fluid loading on flexural wave propagation in a plate in the neighborhood of the critical, or coincidence frequency (The frequency at which the flexural wave speed equals the sound speed). It was learned that there is an abrupt shift in the effects of fluid loading near the critical frequency, particularly noticeable for water and an aluminum plate, which results in significant shifts in damping and on the flexural wave speed. It was also learned that theoretical calculations predicting such effects had been published some twenty years earlier. So far as we know, this was the first experimental confirmation of the effects.

The latest effort, by LT Tekin Kiyar (Ref. 11) was to compare the radiation patterns calculated by Alper and Magrab (Ref. 12) with measurements made in the laboratory. It was found that the major features of the observed radiation patterns agree reasonably well with those calculated theoretically and it is concluded that this computer model should be a useful design tool. An adaptation of Alper's computer program to a computer available to NPS was made by Kiyar.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

It appears that the nature of the clock transducer problem involves several contradictory requirements. The need for near omnidirectionality requires small dimensions while the need for a large source level with the small size places severe mechanical stress on the internal structure of the transducer and the water medium near the radiating face. There is a contradiction between the requirements for simplicity and low cost and the requirement that the transducer operate at full power without the acoustic load.

It seems very likely that the presently used transducers operate at very near the limits of breakdown for available materials. If this is so, then improved reliability will not be achieved by conventional transducer design methods.

Several alternative approaches to reducing the severity of the problem have been considered. One such alternative is to change specifications to include a radiation pattern similar to that of Figure 5, which reduces the power radiated into the central 45 degree cone, which should provide a beneficial increase in efficiency. Although this reduction in required power output is not large, about 30 percent, it should reduce mechanical stress in a device already near its limits and, thereby, help to improve reliability from mechanical failure.

It also appears likely that a further increase in reliability could be achieved if the clock system incorporated a means for interrupting or decreasing the electrical drive power when the torpedo is removed from the water.

The first approach to beam pattern control, using several discrete elements with different phase and amplitudes, offers promise of achieving the objective but at the expense of a rather complex structure. This structure would probably be costly to manufacture in the modest quantities needed.

The experiment of Ford and a similar experiment conducted at Keyport appear also to offer potential for some improvements in the beam pattern. However, the small size of the test is not sufficient to warrant firm conclusions. In addition, the Keyport test indicated poor behavior with the phase shift keying tests, possibly due to a non-uniform frequency response.

The experimental work on the radiation from flexural waves in a plate also shows promise for obtaining a broadened radiation pattern. It was learned that the radiation impedance of the fluid in contact with the plate does have a significant effect on the flexural vibrations of the plate. This approach is worthy of further investigation because it offers a prospect of using the hull itself as the radiating surface. This will probably be necessary if the present methods of acoustic ranging are to be used in testing the newer laminar flow torpedo bodies expected in the future.

Although these approaches have all shown promise of capability for beam pattern control, the work so far has not resulted in a prototype model which could be tested and evaluated on the ranges at Keyport.

There are other alternatives which have not been considered here but which should be considered for possible use in future ranging systems at Keyport. Among these are the use of a sound frequency significantly lower than 75 kHz, the use of more closely spaced acoustic sensors and, perhaps, a combination of these.

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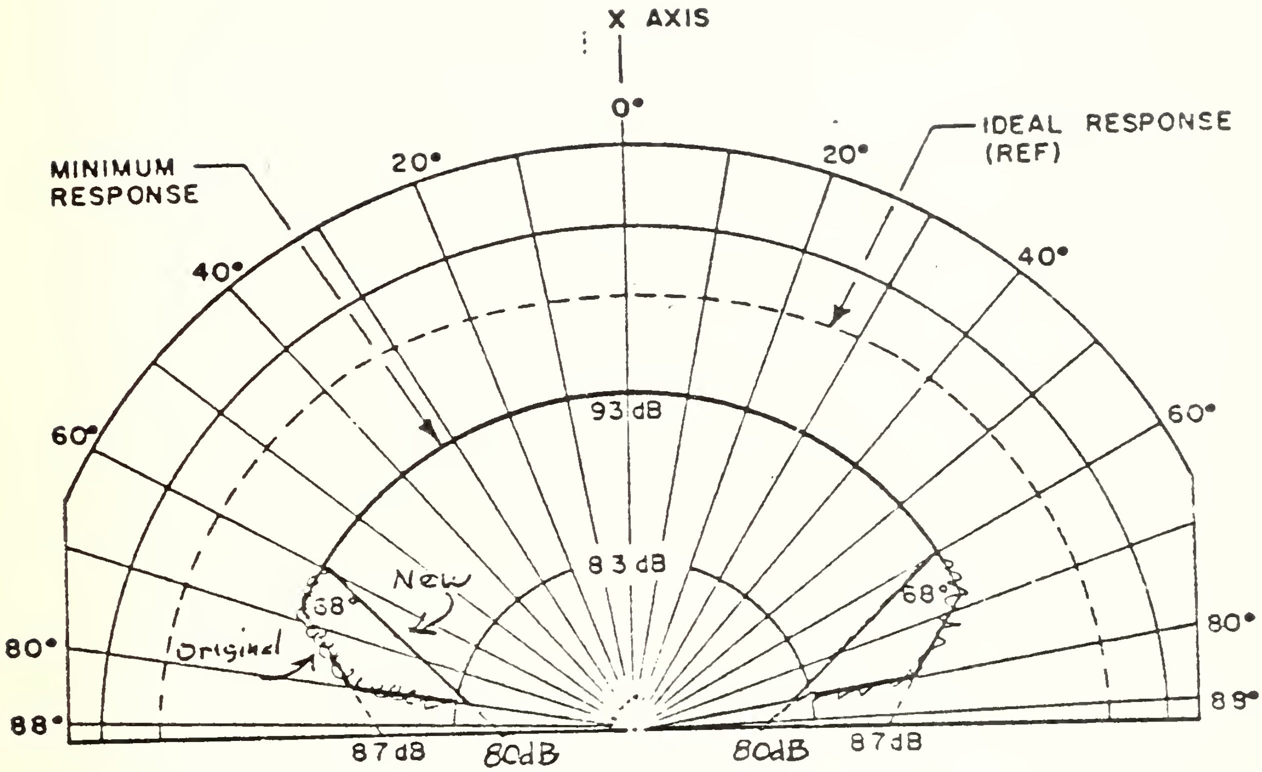

NOTE:
OUTPUT AT ANGLES GREATER THAN 88° UNSPECIFIED.

Fig. 1. Transducer Output Specifications
From NAVORD Drawing 2814382, as Modified on 2/28/73.
[dB are ref. 1 μbar at 1 yard]

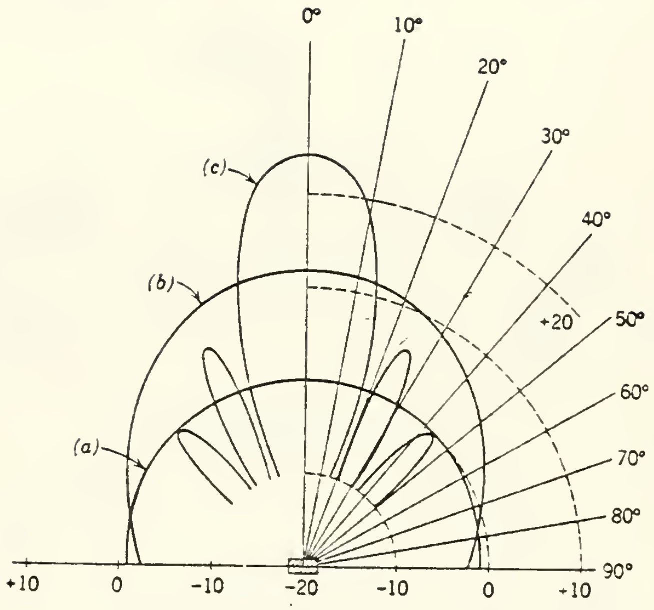

Figure 2. Polar radiation pattern in decibels as a function of angle for a circular piston in an infinite baffle for different values of ka or a/λ.
a) $ka = \pi/4$ or $a/\lambda = 1/8$, b) $ka = \pi$ or $a/\lambda = 1/2$,
c) $ka = 4\pi$ or $a/\lambda = 2$. (From Reference 3)

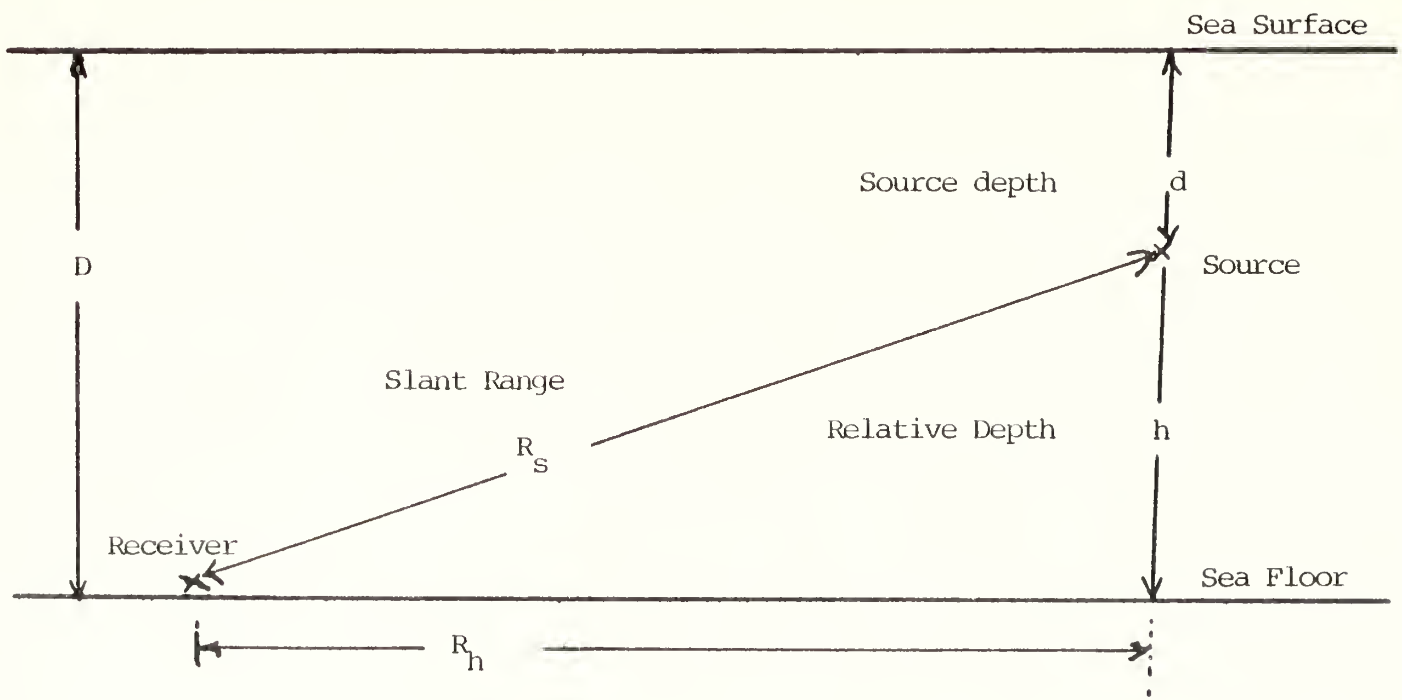

Fig. 3. Geometry for Source-Receiver Relationships

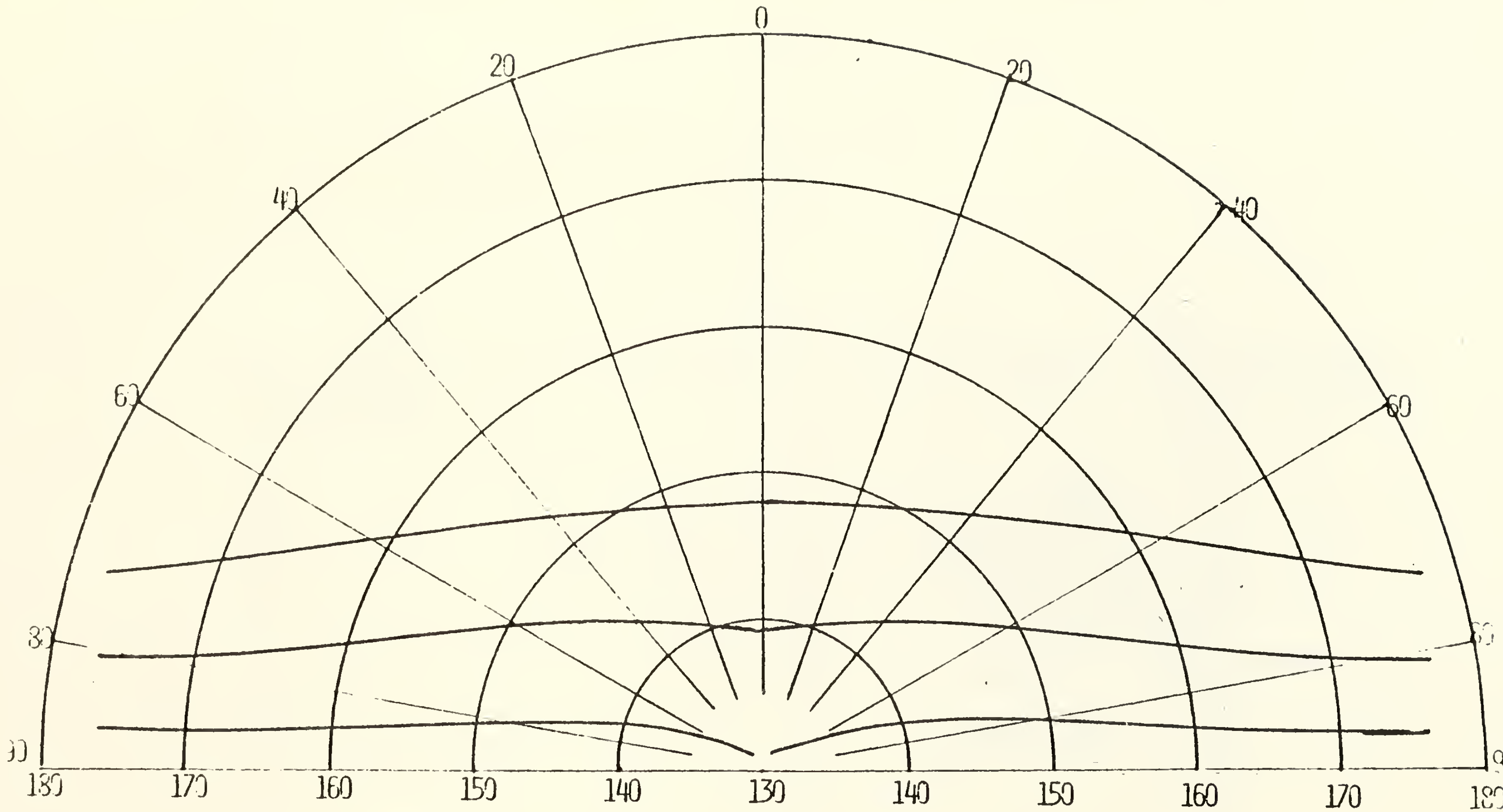

Fig. 4. Minimum required beam pattern and source level from Equation 12. dB ref 1μPa at 1 yard.

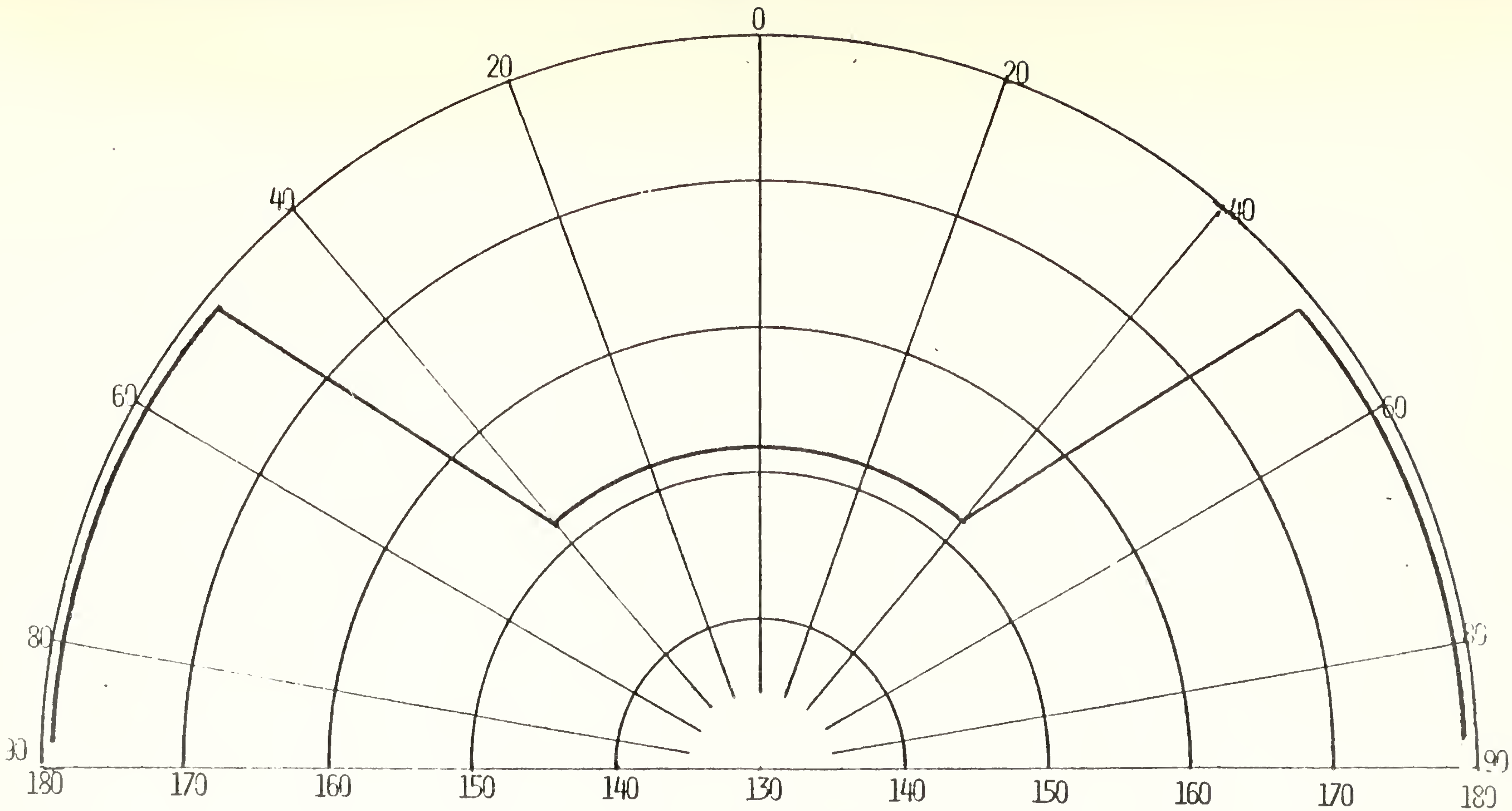

Fig. 5. Suggested specification of clock transducer requirements for beam pattern and source level. In dB ref 1μPa at 1 yard.

APPENDIX A

Several students at NPS have worked on several problems relevant to this transducer development area during the past three years. Abstracts of their M.S. Theses are presented on the following pages.

Roland R. Johnson M.S. Thesis 1974

MODELS FOR COMPUTING THE DIRECTIONAL RADIATION OF SOUND FROM SOURCES ON A RIGID CYLINDRICAL BAFFLE

Abstract

The closed-form equations describing the acoustic radiation pattern for a source flush-mounted on a rigid cylindrical baffle are derived for three sonar transducer design configurations: two rectangular designs (Segment and Patch) and one circular configuration (Disk). The derivation includes both application and an extension of developments by previous theorists. A computer program based on the derived closed-form equations is included to permit design investigation of the three (3) configurations. Preliminary results of the program agree with previously obtained patterns by other investigators for the same source. The program, however, allows extension to new configurations.

A.H.P. Shaw M.S. Thesis December 1975

RADIATION PATTERN SHAPING OF A TWO-ELEMENT CONCENTRIC RING TRANSDUCER USING PHASE AND AMPLITUDE SHADING

Abstract

A high-frequency transducer which gives usefully uniform radiation into a half space is required for use as a target locator in an underwater acoustic range. Phase and amplitude shading of a two-element transducer consisting of a central circular piston and a concentric annular ring has been proposed to meet the requirement. A transducer resonant at 74 kHz but scaled in terms of wavelength to 25 kHz in the transverse dimension has been constructed and tested at both frequencies. Exceptionally wide radiation patterns with major lobe widths of the order of 150 degrees (10 dB down) were obtained. At the scaled frequency computer model predictions based on simple theory agreed well with the measured radiation patterns. At the resonant frequency, however, predicted secondary lobe details were not found in the patterns. These discrepancies have been attributed to the non-uniform motion of the radiating surfaces due to mutual coupling effects through the transducer structure and the transmission medium. In spite of these minor problems associated with the prototype transducer, promising results have been obtained and have shown the design concept to be a valid and viable one.

V.U. Auns M.S. Thesis December 1976

DEVELOPMENT OF A CONCENTRIC PISTON TRANSDUCER FOR TRACKING UNDERWATER VEHICLES

Abstract

The use of amplitude and phase shading on a pair of concentric piston radiators has been employed as a means for controlling the acoustic radiation patterns for a small flush face transducer which is intended for use as a 75 kHz sound source in the underwater tracking of vehicles. A description is given of the design, construction and tests of several models of the composite piezoelectric ceramic transducer. Results indicate that this appears to be a feasible method for achieving a principal design goal of a broad beamwidth radiation pattern with a pronounced reduction in source level along the transducer axis. Some additional development is needed for achieving a configuration which might be optimum for production.

A.L. Ford, III M.S. Thesis December 1976

AN EXPERIMENT USING REFRACTIVE PROPERTIES OF AN ENCAPSULANT TO ALTER THE SOUND RADIATION PATTERN IN A SMALL FLUSH-FACE TRANSDUCER

Abstract

A preliminary experiment is described in which a compound of high index of refraction is used to obtain a broad beam width sound radiation pattern in water from a small transducer element, resonant at 75 kHz, located in a flush-face mounting in a plane baffle. It is demonstrated that the resultant radiation pattern is significantly broader than that typical of current production transducers using identical transducer elements but with a different encapsulant. Due to the limited number of experimental test configurations, it is not possible to determine with certainty the significance of the index of refraction of the encapsulant.

O. Sevdik M.S. Thesis December 1976

DEVELOPMENT OF A FLEXURAL DISK TRANSDUCER FOR ACOUSTIC TRACKING OF UNDERWATER VEHICLES

Abstract

A high frequency, broad-band transducer which has a broad radiation pattern in a half space is required for acoustic tracking of underwater vehicles. Two models of a flexural disk transducer were built and tested. It was found that the radiation loading in water completely damps the resonances due to standing flexural waves and the radiation appears to be due entirely to flexural waves propagating in the disk. Broad-band radiation patterns and broad bandwidth (60 - 80 kHz) were obtained. The discrepancies between theory and experiment are attributed in part to violation of the thin plate assumptions and to lack of knowledge of the actual velocity distributions. This approach offers promise for achieving the desired broad beam widths. However, additional development work is needed to obtain a transducer which has the curved face necessary for smooth hydrodynamic flow.

EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF FLUID LOADING ON FLEXURAL WAVES IN PLATES

Abstract

An experimental investigation was conducted of the effects of fluid loading on axially symmetric flexural waves in a circular aluminum plate 25 in in diameter and 5/16 in thick. Measurements were made of the flexural wavelength and natural frequencies with the plate in air, and with water loading on one side, over a frequency range from 20 kHz to 80 kHz. The critical (coincidence) frequency, that frequency at which the speed of the flexural wave equals the speed of sound in water, occurs at approximately 45 kHz. The measured flexural-wave speeds with air loading are in good agreement with theory. With water loading, the wave speed decreases, the amount of decrease increasing to approximately 14 percent below the in-air value just below the critical frequency. At the critical frequency, the wave speed appears to jump to values nearly equal to the unloaded values. Radiation patterns were obtained and when edge effects are eliminated, are in qualitative agreement with theoretical predictions for an infinite fluid-loaded plate.

T.O. Kiyar M.S. Thesis December 1978

COMPARISON OF THEORETICAL AND EXPERIMENTAL SOUND RADIATION PATTERNS FROM A WATER LOADED FLEXURAL DISK TRANSDUCER

Abstract

Measurements of the sound radiation patterns in water from the flexural vibrations of a clamped-edge steel disk have been made and are compared with the results of theoretical calculations made by Alper and Magrab (Journal of Acoustical Society of America, Vol. 48, Number 3, pp. 681-691, 1970) for the two lowest order circularly symmetric modes of disk vibration. Although some differences were expected and were found due to the experimental condition which only approximated the assumptions made in the theory, it was found that the major features of the measured patterns agreed reasonably well with the theoretical pattern. The results have applicability to the design of sound source which could be used in underwater tracking of vehicles on a test range.

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